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HIGH FREQUENCY MAGNETOIMPEDANCE OF FeNi/Cu/FeNi SENSITIVE ELEMENTS WITH DIFFERENT GEOMETRIES

S.O. Volchkov [1, a], A.V. Svalov [1,b] and G.V. Kurlyandskaya [1,c]

[1] Ural State University named under A.M.Gorky , Dept. Magnetism and Magnetic Nanomaterials, Lenin Ave. 51, 620083, Ekaterinburg, Russian Ferderation

[a] stanislav.volchkov@usu.ru, [b]andrey.svalov@usu.ru, [c]galina.kurlyandskaya@usu.ru

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Abstract. In this work magnetoimpedance (MI) behaviour was studied experimentally for $Fe_{19}Ni_{81}$(175 nm)/Cu(350 nm)/$Fe_{19}Ni_{81}$(175 nm) sensitive elements deposited by rf-sputtering. A constant magnetic field was applied in plane of the sandwiches during deposition perpendicular to the Cu-lead in order to induce a magnetic anisotropy. Sandwiches with different width (w) of FeNi parts were obtained. The complex impedance was measured as a function of the external magnetic field for a frequency range of 1 MHz to 700 MHz for MI elements with different geometries. Some of MI experimental data are comparatively analysed with finite elements numerical calculations data. The obtained results can be useful for optimization of the design of miniaturized MI detectors.

Introduction

Magnetoimpedance (MI) is the change of the high frequency impedance of a soft ferromagnet under application external magnetic field [1-4]. Mathematical description of the magnetoimpedance phenomenon requires analytical solution of the Maxwellrs equations that can be done only for simplest geometries and using approximations [5-7]. For example, analytical solution is impossible in case of MI sandwiched structure ferromagnet/conductor/ferromagnet for narrower central conductive part. The finite elements method (FEM) was proposed as useful numerical method for complex geometry of MI sensitive elements [8-9].

In this work the longitudinal MI behaviour was studied for $Fe_{19}Ni_{81}$/Cu/$Fe_{19}Ni_{81}$ and $Fe_{19}Ni_{81}$/$Fe_{19}Ni_{81}$ multilayered sensitive elements of different width in a geometry most appropriate for whole cell type biodetectors. Frequency dependencies of experimental MI ratios measured at reasonably low frequencies, convenient for technological applications are comparatively analysed with FEM numerical calculations data.

Experimental

The multilayered FeNi/Cu/FeNi and FeNi/FeNi multilayered sensitive elements were deposited onto glass substrates at room temperature by rf-sputtering. The deposition speed was $V_{Fe\text{-}Ni} = 0.38$ nm/s for Permalloy ($Fe_{19}Ni_{81}$) and $V_{Cu} = 0.22$ nm/s for copper. Between the deposition of each layer (including deposition of FeNi/FeNi multilayered elements) a technological 10 min stop was made for surface passivation. MI elements had following dimensions: 1 mm × 8.2 mm with square contacts terminations of 2 mm × 2 mm for copper part; lengths of magnetic parts was kept constant being of 8 mm. Sandwiches with different width (w) of FeNi parts and two layered FeNi/FeNi structures were obtained (see Table and Fig. 1(a)). During multilayered structures deposition a constant magnetic field of about 100 Oe was applied in plane of the samples and perpendicular to the Cu-lead, creating a transverse anisotropy. For example, the anisotropy field $H_k \approx 8$ Oe for S1 sample being estimated from the shape M(H) curves obtained by MOKE studies.

The complex impedance of the samples (absolute value of the total impedance (Z), real (R) and imaginary (X) components) was measured as a function of the external magnetic field for a frequency (f) range of 1 MHz to 700 MHz for MI elements with different geometries. The sample

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Table . Description of the multilayered samples

Simple	MI multilayered structure	Width (mm)	Type of the structure
S1	$Fe_{19}Ni_{81}$(175 nm)/Cu(350 nm)/$Fe_{19}Ni_{81}$(175 nm)	$w_1 = 12$	Experimental
S2	$Fe_{19}Ni_{81}$(175 nm)/Cu(350 nm)/$Fe_{19}Ni_{81}$(175 nm)	$w_2 = 9$	Experimental
S3	$Fe_{19}Ni_{81}$(175 nm)/Cu(350 nm)/$Fe_{19}Ni_{81}$(175 nm)	$w_3 = 6$	Experimental
S4	$Fe_{19}Ni_{81}$(175 nm)/Cu(350 nm)/$Fe_{19}Ni_{81}$(175 nm)	$w_4 = 3$	Experimental
S5	$Fe_{19}Ni_{81}$(175 nm)/Cu(350 nm)/$Fe_{19}Ni_{81}$(175 nm)	$w_5 = 1$	Model
S6	$Fe_{19}Ni_{81}$(175 nm)/$Fe_{19}Ni_{81}$(175 nm)	$w_6 = 3$	Experimental

was connected by conductive silver paint to the microstrip line with 50 Ω of characteristic impedance and the complete test fixture was situated between the two microstrip lines terminated in SMA connectors. The magnetoimpedance was measured using impedance Network Analyzer (Agilent E8358A) by method described in Ref [10]. MI ratios were defined as follow: $\Delta Z/Z = (Z(H) - Z(H = 0))/Z(H = 0)$, $\Delta R/R = (R(H) - R(H = 0))/R(H = 0)$ and $\Delta X/X = (X(H) - X(H = 0))/X(H = 0)$. The sensitivities with respect to applied field was defined as follow: **s(**$\Delta Z/Z$) = $d(\Delta Z/Z)/dH$ and **s(**$\Delta R/R$) = $d(\Delta R/R)/dH$.

Results and discussion

Fig 1(b). shows the example of field dependence of R and Z components of total impedance for selected frequency of 500 MHz. The same dependences were obtained and analyzed in order to collect the maximum values of $\Delta Z/Z$, $\Delta R/R$ and $\Delta X/X$ ratios ($\Delta Z/Z_{max}$, $\Delta R/R_{max}$ and $\Delta X/X_{max}$) which for low frequencies appeared in the field closed to H_k. The increase of the frequency resulted in the shift of the maxima toward the higher fields. Decrease of the width *w* for the same width of the conductive lead results in significant increase of the MI ratio. Rather complex shape of X(H)

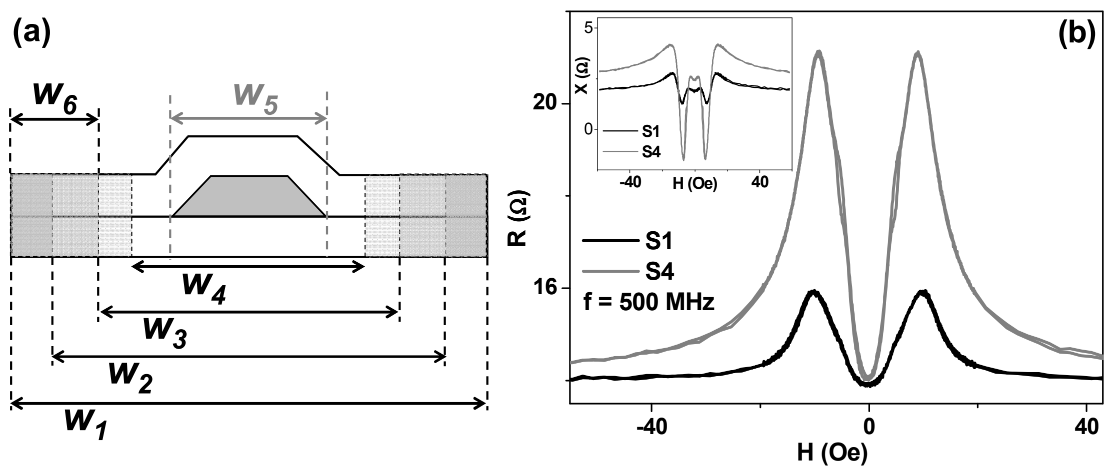

Figure 1. Schematic description (cross section) of MI multilayered structures used for magnetic, MI measurements and modeling (a); examples of the field dependence of real (main graphs) and imaginary components (inset) of FeNi/Cu/FeNi sensitive elements of different widths.

curves can be explained not only by a proximity to the resonance phenomenon at f = 500 MHz, but also taking into account the size of the circuit and appearance of propogative electric contributions, which first of all affect the imaginary components [10-11]. Therefore only R and Z behaviors were analyzed in details.

Fig. 3 gives the summary of the frequency dependencies of $\Delta Z/Z$ and $\Delta R/R$ ratios of FeNi/Cu/FeNi structures: it contains both experimental data and results of the mathematical approximation. Fig.3(a) shows an example of the widths dependence of $\Delta R/R_{max}$ for selected frequency. The exponential grows is clearly seen from the fit of the experimental points. Samples S1-S4 were easy to fabricate with the same shape. At the same time it was difficult to obtain exactly the same geometry as shown in Fig. 1. Therefore it was supposed that $\Delta R/R_{max}$ or $\Delta Z/Z_{max}$ value can be calculated for each frequency using the fit curve of the experimental data for S1-S4 samples. Fig. 3b shows that for all frequencies under consideration a decrease of the width *w* results in significant increase of the MI ratio which was most high for a magnetic structure with smallest width but still close magnetic flux. It is interesting to mention, that different result was obtained on the basis of pure FEM simulations [8] variation of pure width to thickness ratio from 4 to 50 (in present work this parameters varies from 3.4×10^3 for S1 to 2.9×10^4 for S4 sample). In work [8] no influence of the width on MI maximum value was found.

Fig. 4. shows comparison of the experimentally obtained MI responses of the samples S4 (were MI is most high with $\Delta R/R_{max}$ up to 52%) and samples S6 (FeNi/FeNi structures of the same width with $\Delta R/R_{max}$ up to 14%). Although the $\Delta R/R_{max}$ and $\Delta Z/Z_{max}$ values for S4 samples are significantly higher in all frequency range, it is important to mention that FeNi/FeNi structures also shows MI effect of order of 10%. The maximum sensitivity for multilayred structure S4 was about 6%/Oe for f = 400 MHz. The appearance of non-zero MI effect in a relatively low frequency range of 10 to 700 MHz in part can be understood taking into account the employed deposition technology. In fact, FeNi (175 nm)/FeNi (175 nm) S6 multilayered structure is not equivalent to the FeNi(350 nm) single layered thin film. Technological stop between the depositions of different layers leads to a passivation of the surface and most probably blocks the columnar structure grow and appearance of the out of plane magnetization component in magnetic layers.

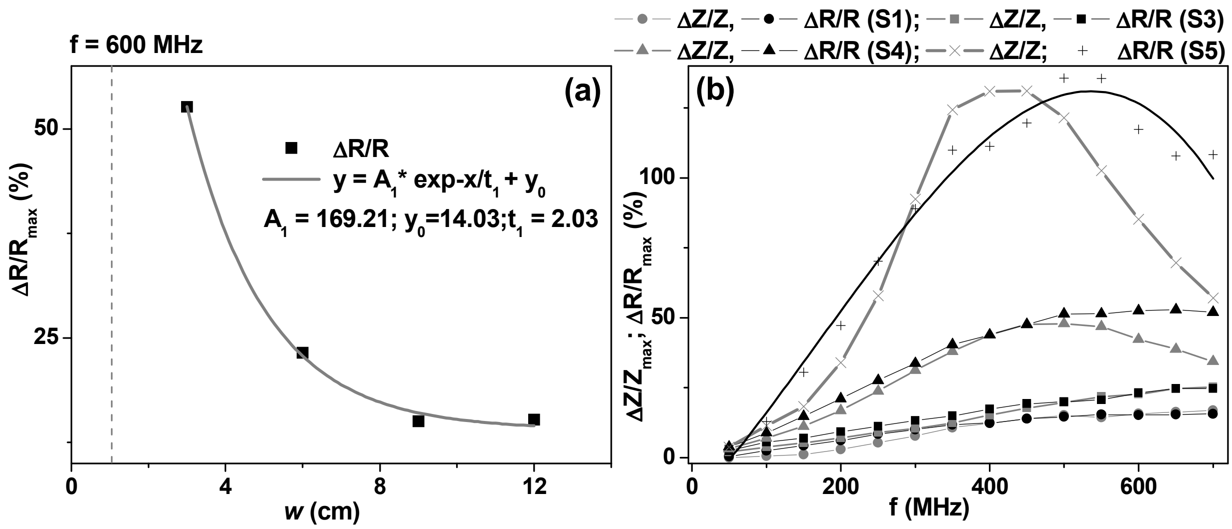

Figure 3. Example of the experimental dependence and exponential fit of maximum value of MI of FeNi/Cu/FeNi sensitive elements on their width (a); experimental and calculated frequency dependences of maximum MI ratios for FeNi/Cu/FeNi sensitive elements of different width.

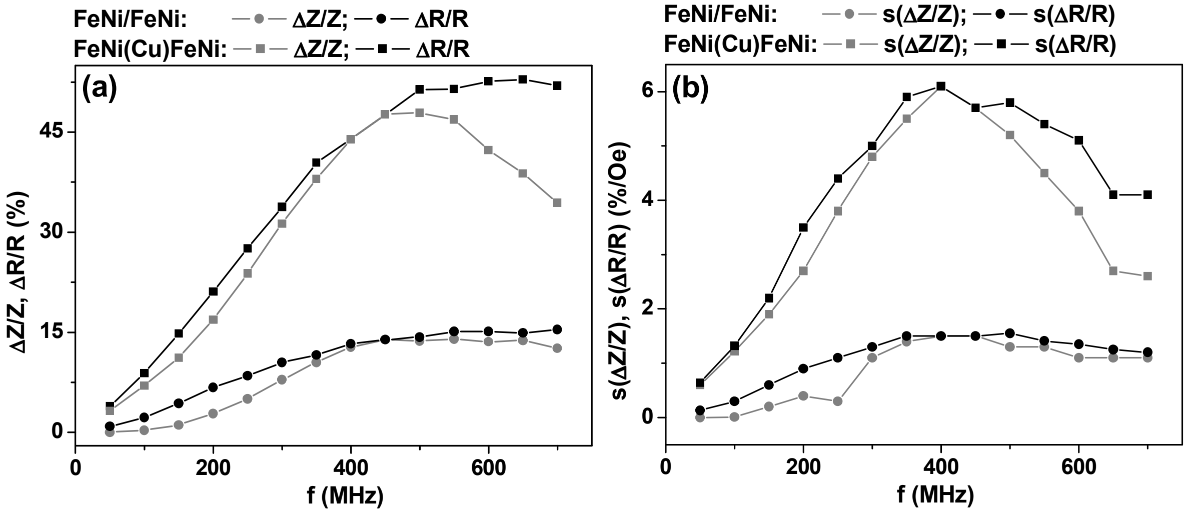

Figure 4. Experimental frequency dependences of FeNi/Cu/FeNi (S4) and FeNi/FeNi (S6) MI sensitive elements of the same width $w_4 = w_6 =$ 3 mm (a); experimental frequency dependence of the MI sensitivities for S4 and S6 samples.

Summary

MI behaviour was studied in FeNi(175 nm)/Cu(350 nm)/FeNi(175 nm) sensitive elements with different width of FeNi parts (w of 1 to 12 mm) and FeNi(175 nm)/FeNi(175 nm) two-layered films in a frequency range of 1 MHz to 700 MHz. For all frequencies under consideration a decrease of the width results in significant increase of the MI ratio. The obtained results can be useful for optimization of the design of miniaturized magnetic field detectors and biosensors.

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